

Annex I

Methodology for Estimating Methane Emissions from Manure Management

The following steps were used to estimate methane emissions from the management of livestock manure.

Step 1: Collect Livestock Population Data

All livestock population data, except for horses, were taken from U.S. Department of Agriculture (USDA) statistical reports. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System website, at <<http://www.mannlib.cornell.edu/usda/>>, while historical data were downloaded from the USDA National Agricultural Statistics Service (NASS) website at <<http://www.usda.gov/nass/pubs/dataprd1.htm>>.

Dairy cow and swine population data by farm size for each state, used in the weighted methane conversion factor (MCF) calculation described in Step 2, were found in the *1992 Census of Agriculture* published by the U.S. Department of Commerce (DOC 1995), and the *1997 Census of Agriculture* published by the USDA (1999n). This census is conducted every five years. Data from the census is available at the USDA NASS website at <<http://www.nass.usda.gov/census/>>.

The Food and Agriculture Organization (FAO) publishes horse population data. These data were accessed from the FAOSTAT database at <<http://apps.fao.org/>>. Table I-1 summarizes the published population data by animal type.

Step 2: Estimate State Methane Conversion Factors for Dairy Cows and Swine

EPA (1992) provides an assessment of dairy and swine manure management practices used to estimate emissions for 1990. Based on this assessment and the relationship between farm sizes and manure management systems, an average weighted MCF was assigned to each dairy and swine farm size category. These weighted MCFs indicate the portion of the methane producing potential realized for each category. MCFs applied to larger farms were higher than those applied to smaller farm sizes because larger farms tend to use liquid manure management systems, which produce more methane.

Using the dairy cow and swine populations by farm size in the 1992 and 1997 *Census of Agriculture* for each state, weighted average dairy and swine MCFs were calculated for each state for each of these years. This weighted MCF value represents the mix of manure management practices in each state. The overall increase in average state MCFs between 1992 and 1997 is caused by a shift in dairy cow and swine populations towards larger facilities, which reflects the increasing use of liquid systems.

Calculated weighted MCFs for 1992 were used for 1990 and 1991. The calculated weighted MCFs for 1997 were used for 1998. MCF values for the years in between (i.e., 1993 through 1996) were calculated by interpolating between the two sets of calculated weighted MCFs. Table I-2 and Table I-3 present the weighted dairy and swine MCF values for each year.

Step 3: Estimate Methane Emissions from Swine

For each state, the total swine population was multiplied by volatile solids (VS) production rates to determine total VS production. Estimated state level emissions were calculated as the product of total VS production in each year multiplied by the maximum methane production potential for swine manure (B_o), and the weighted average state MCF for the corresponding year. Total U.S. emissions are the sum of the state level emissions. The VS production rate and maximum methane production potential are shown in Table I-4.

Step 4: Estimate Methane Emissions from Dairy Cattle

Methane emissions from dairy cow manure were estimated using the same method as emissions from swine (Step 3), but with an added analysis to estimate changes in manure production associated with changes in feed intake, or dry matter intake (DMI). It is assumed that manure and VS production will change linearly with changes in dry matter intake (DMI).

Changes in DMI were calculated reflecting changes in feed intake associated with changes in milk production per cow per year. To estimate the changes in feed intake, a simplified emission factor model was used for dairy cow enteric fermentation emissions (see Annex H). This model estimates the change in DMI over time relative to 1990, which was used to calculate VS production by dairy cows by state, as summarized in the following equation: (Dairy cow population) ´ (VS produced per cow) ´ (DMI scaling factor). Methane emissions were then calculated as follows: (VS produced) ´ (Maximum methane production potential for dairy cow manure) ´ (State-specific MCF). Total emissions were finally calculated as the sum of the state level emissions. The 1990 VS production rate and maximum methane production potential are shown in Table I-4.

Step 5: Estimate Methane Emissions for Other Animals

The 1990 methane emissions for the other animal types were estimated using the detailed method described in EPA (1993). This approach is based on animal-specific manure characteristics and management system data. This process was not repeated for subsequent years for these other animal types. Instead, national populations of each of the animal types were used to scale the 1990 emissions estimates to the period 1991 through 1999.

Emission estimates are summarized in Table I-5.

Table I-1: Livestock Population (1,000 Head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cattle	14,143	13,980	13,830	13,767	13,566	13,502	13,305	13,138	12,992
Dairy Cows	10,007	9,883	9,714	9,679	9,504	9,491	9,410	9,309	9,200
Dairy Heifers	4,135	4,097	4,116	4,088	4,062	4,011	3,895	3,829	3,793
Swine	53,941	56,478	58,532	58,016	59,951	58,899	56,220	58,728	62,043
Market	47,042	49,247	51,276	50,859	52,669	51,973	49,581	51,887	55,192
Breeding	6,898	7,230	7,255	7,156	7,282	6,926	6,639	6,839	6,850
Beef Cattle	86,064	87,265	88,545	90,319	92,570	94,390	94,269	92,290	90,730
Feedlot Steers	7,252	7,927	7,404	7,841	8,034	7,625	7,806	7,943	8,199
Feedlot Heifers	3,749	4,142	3,882	4,091	4,111	3,921	4,049	4,108	4,238
Feedlot	89	100	94	99	101	99	99	99	98
Cow/Other									
NOF Bulls	2,180	2,198	2,220	2,239	2,306	2,392	2,392	2,325	2,235
NOF Calves	23,909	23,854	24,118	24,209	24,586	25,170	25,042	24,363	24,001
NOF Heifers	8,744	8,831	9,263	9,730	10,323	10,805	10,819	10,768	10,219
NOF Steers	7,552	7,355	8,206	8,079	8,109	8,831	8,651	8,153	7,696
NOF Cows	32,588	32,860	33,358	34,032	35,000	35,545	35,411	34,530	34,044
Sheep	11,356	11,174	10,797	10,201	9,825	8,982	8,458	8,015	7,817
Ewes > 1yr	7,961	7,799	7,556	7,140	6,839	6,256	5,898	5,595	5,481
Rams/Weth >	369	361	350	331	315	286	270	253	249
1yr									
Ewes < 1yr	1,491	1,464	1,432	1,349	1,287	1,179	1,110	1,053	1,038
Rams/Weth <	381	373	366	348	332	298	282	261	261
1yr									
Sheep on Feed	1,154	1,177	1,093	1,032	1,052	964	898	853	788
Goats	2,545	2,475	2,645	2,605	2,605	2,495	2,545	2,295	2,045
Poultry	1,703,036	1,767,513	1,832,308	1,895,851	1,966,050	2,034,213	2,096,618	2,147,851	2,189,254
Hens > 1yr	119,551	117,178	121,103	131,688	135,094	133,841	138,048	140,966	150,778
Pullets laying	153,916	162,943	163,397	158,938	163,433	165,230	165,874	171,171	169,916
Pullets > 3mo	34,222	34,272	34,710	33,833	33,159	34,004	33,518	35,578	39,664
Pullets < 3mo	38,945	42,344	45,160	47,941	46,694	47,365	48,054	54,766	56,054
Chickens	6,545	6,857	7,113	7,240	7,369	7,637	7,243	7,549	7,682
Broilers	1,172,83	1,227,43	1,280,49	1,338,86	1,403,50	1,465,13	1,519,35	1,552,84	1,586,85
0	0	8	2	8	4	2	0	6	
Other (Lost)	6,971	7,278	7,025	6,992	7,124	12,212	12,072	9,851	10,686
Other (Sold)	41,672	39,707	41,538	39,606	39,402	35,901	34,860	38,197	38,754
Turkeys	128,384	129,505	131,764	130,750	130,266	132,889	137,597	136,932	128,865
Horses	5,650	5,650	5,850	5,900	6,000	6,000	6,050	6,150	6,150

Table I-2: Dairy Cow Weighted MCF Values

State	1990	1991	1992	1993	1994	1995	1996	1997	1998
Alabama	0.23	0.23	0.23	0.22	0.20	0.19	0.18	0.16	0.16
Alaska	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Arizona	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Arkansas	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
California	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Colorado	0.31	0.31	0.31	0.33	0.35	0.37	0.38	0.40	0.40
Connecticut	0.19	0.19	0.19	0.20	0.21	0.22	0.22	0.23	0.23
Delaware	0.21	0.21	0.21	0.20	0.19	0.19	0.18	0.18	0.18
Florida	0.41	0.41	0.41	0.42	0.42	0.43	0.43	0.44	0.44
Georgia	0.27	0.27	0.27	0.28	0.29	0.30	0.31	0.32	0.32
Hawaii	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Idaho	0.23	0.23	0.23	0.26	0.29	0.32	0.36	0.39	0.39
Illinois	0.07	0.07	0.07	0.07	0.08	0.09	0.10	0.11	0.11
Indiana	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.10
Iowa	0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.09
Kansas	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Kentucky	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08
Louisiana	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Maine	0.10	0.10	0.10	0.11	0.11	0.12	0.13	0.13	0.13
Maryland	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17	0.17
Massachusetts	0.13	0.13	0.13	0.13	0.14	0.15	0.15	0.16	0.16
Michigan	0.12	0.12	0.12	0.14	0.15	0.17	0.18	0.20	0.20
Minnesota	0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.09
Mississippi	0.17	0.17	0.17	0.18	0.19	0.19	0.20	0.21	0.21
Missouri	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09
Montana	0.16	0.16	0.16	0.17	0.18	0.19	0.20	0.21	0.21
Nebraska	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.10	0.10
Nevada	0.36	0.36	0.36	0.38	0.39	0.40	0.42	0.43	0.43
New Hampshire	0.12	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.17
New Jersey	0.13	0.13	0.13	0.14	0.14	0.15	0.16	0.16	0.16
New Mexico	0.42	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45
New York	0.11	0.11	0.11	0.12	0.14	0.16	0.18	0.19	0.19
North Carolina	0.20	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.24
North Dakota	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Ohio	0.07	0.07	0.07	0.08	0.09	0.09	0.10	0.11	0.11
Oklahoma	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.14
Oregon	0.25	0.25	0.25	0.27	0.29	0.31	0.33	0.35	0.35
Pennsylvania	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.10
Rhode Island	0.07	0.07	0.07	0.06	0.04	0.03	0.02	0.01	0.01
South Carolina	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
South Dakota	0.06	0.06	0.06	0.07	0.08	0.08	0.09	0.09	0.09
Tennessee	0.14	0.14	0.14	0.14	0.15	0.16	0.16	0.17	0.17
Texas	0.31	0.31	0.31	0.32	0.33	0.34	0.35	0.37	0.37
Utah	0.21	0.21	0.21	0.23	0.25	0.27	0.29	0.30	0.30
Vermont	0.11	0.11	0.11	0.13	0.14	0.16	0.17	0.18	0.18
Virginia	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19
Washington	0.29	0.29	0.29	0.31	0.33	0.35	0.38	0.40	0.40
West Virginia	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.13
Wisconsin	0.05	0.05	0.05	0.06	0.07	0.08	0.09	0.10	0.10
Wyoming	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14

Table I-3: Swine Weighted MCF Values

State	1990	1991	1992	1993	1994	1995	1996	1997	1998
Alabama	0.15	0.15	0.15	0.19	0.22	0.25	0.29	0.32	0.32
Alaska	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Arizona	0.44	0.44	0.44	0.35	0.27	0.18	0.10	0.01	0.01
Arkansas	0.37	0.37	0.37	0.38	0.39	0.40	0.41	0.42	0.42
California	0.28	0.28	0.28	0.30	0.33	0.35	0.38	0.40	0.40
Colorado	0.28	0.28	0.28	0.29	0.30	0.31	0.32	0.33	0.33
Connecticut	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Delaware	0.19	0.19	0.19	0.16	0.12	0.08	0.05	0.01	0.01
Florida	0.13	0.13	0.13	0.11	0.09	0.06	0.04	0.01	0.01
Georgia	0.19	0.19	0.19	0.20	0.22	0.23	0.24	0.25	0.25
Hawaii	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Idaho	0.16	0.16	0.16	0.13	0.10	0.07	0.04	0.01	0.01
Illinois	0.23	0.23	0.23	0.25	0.27	0.28	0.30	0.32	0.32
Indiana	0.25	0.25	0.25	0.26	0.28	0.29	0.31	0.32	0.32
Iowa	0.20	0.20	0.20	0.23	0.25	0.28	0.30	0.32	0.32
Kansas	0.18	0.18	0.18	0.20	0.22	0.24	0.27	0.29	0.29
Kentucky	0.17	0.17	0.17	0.20	0.23	0.27	0.30	0.33	0.33
Louisiana	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Maine	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Maryland	0.25	0.25	0.25	0.24	0.23	0.23	0.22	0.21	0.21
Massachusetts	0.26	0.26	0.26	0.21	0.16	0.11	0.06	0.01	0.01
Michigan	0.24	0.24	0.24	0.26	0.28	0.30	0.32	0.34	0.34
Minnesota	0.20	0.20	0.20	0.23	0.26	0.28	0.31	0.34	0.34
Mississippi	0.21	0.21	0.21	0.25	0.29	0.33	0.37	0.42	0.42
Missouri	0.17	0.17	0.17	0.20	0.22	0.25	0.27	0.30	0.30
Montana	0.23	0.23	0.23	0.26	0.30	0.33	0.36	0.40	0.40
Nebraska	0.18	0.18	0.18	0.20	0.22	0.24	0.26	0.28	0.28
Nevada	0.32	0.32	0.32	0.26	0.20	0.14	0.07	0.01	0.01
New Hampshire	0.24	0.24	0.24	0.19	0.15	0.10	0.06	0.01	0.01
New Jersey	0.14	0.14	0.14	0.12	0.09	0.06	0.04	0.01	0.01
New Mexico	0.30	0.30	0.30	0.25	0.19	0.13	0.07	0.01	0.01
New York	0.13	0.13	0.13	0.16	0.20	0.24	0.28	0.32	0.32
North Carolina	0.42	0.42	0.42	0.42	0.43	0.43	0.44	0.45	0.45
North Dakota	0.10	0.10	0.10	0.14	0.17	0.21	0.24	0.28	0.28
Ohio	0.15	0.15	0.15	0.17	0.19	0.21	0.23	0.25	0.25
Oklahoma	0.18	0.18	0.18	0.24	0.29	0.34	0.39	0.44	0.44
Oregon	0.20	0.20	0.20	0.19	0.18	0.18	0.17	0.16	0.16
Pennsylvania	0.19	0.19	0.19	0.22	0.25	0.28	0.31	0.34	0.34
Rhode Island	0.38	0.38	0.38	0.31	0.23	0.16	0.08	0.01	0.01
South Carolina	0.24	0.24	0.24	0.27	0.30	0.33	0.36	0.39	0.39
South Dakota	0.12	0.12	0.12	0.15	0.18	0.21	0.24	0.27	0.27
Tennessee	0.15	0.15	0.15	0.18	0.20	0.23	0.26	0.28	0.28
Texas	0.18	0.18	0.18	0.15	0.11	0.08	0.05	0.01	0.01
Utah	0.19	0.19	0.19	0.24	0.29	0.34	0.39	0.44	0.44
Vermont	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Virginia	0.19	0.19	0.19	0.23	0.27	0.31	0.36	0.40	0.40
Washington	0.19	0.19	0.19	0.19	0.20	0.21	0.22	0.22	0.22
West Virginia	0.06	0.06	0.06	0.05	0.04	0.03	0.02	0.01	0.01
Wisconsin	0.14	0.14	0.14	0.15	0.17	0.19	0.20	0.22	0.22
Wyoming	0.10	0.10	0.10	0.08	0.06	0.05	0.03	0.01	0.01

Table I-4: Dairy Cow and Swine Constants

Description	Dairy Cow	Market Swine	Breeding Swine	Source
Typical Animal Mass (kg)	640	116	181	ASAE (1999)
kg VS/day per 1000 kg mass	10	8.5	8.5	ASAE (1999)
Maximum Methane Generation Potential (B _n) m ³ methane/kg VS	0.24	0.47	0.47	EPA (1992)

Table I-5: CH₄ Emissions from Livestock Manure Management (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cattle	746.8	750.8	762.2	791.3	843.4	863.5	895.8	940.5	933.4
Dairy Cows	580.9	586.5	597.1	627.3	680.5	702.7	739.6	786.9	781.2
Dairy Heifers	165.9	164.3	165.1	164.0	162.9	160.9	156.2	153.6	152.1
Swine	1,371.1	1,450.9	1,522.9	1,667.6	1,893.9	2,031.3	2,106.2	2,348.5	2,475.0
Market	1,116.	1,180.	1,248.	1,367.	1,558.	1,682.	1,744.	1,950.	2,073.
	6	8	1	4	0	5	7	3	6
Breeding	254.5	270.1	274.8	300.1	336.0	348.8	361.5	398.2	401.4
Beef Cattle	200.5	205.0	206.3	212.1	218.9	221.1	228.8	228.5	232.7
Feedlot Steers	28.2	31.0	29.1	31.0	31.5	30.1	34.6	33.1	36.7
Feedlot Heifers	16.0	17.7	16.7	17.6	18.7	18.0	21.5	21.0	22.3
Feedlot	0.4	0.5	0.4	0.4	0.6	0.6	0.7	0.7	0.7
Cow/Other									
NOF Bulls	6.5	6.6	6.7	6.7	6.9	7.2	7.3	7.1	7.0
NOF Calves	19.3	19.0	19.3	19.4	19.7	20.1	20.0	19.7	19.6
NOF Heifers	15.7	15.7	16.4	17.3	18.5	19.6	19.7	20.7	20.7
NOF Steers	14.2	13.5	15.2	15.1	15.0	16.2	15.2	17.3	16.3
NOF Cows	100.2	100.9	102.5	104.6	108.0	109.4	109.9	108.9	109.4
Sheep	3.8	3.7	3.6	3.4	3.3	3.0	2.8	2.6	2.6
Ewes > 1 yr	3.1	3.0	2.9	2.7	2.6	2.4	2.3	2.1	2.1
Rams/Weth > 1 yr	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ewes < 1 yr	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rams/Weth < 1 yr	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Sheep on Feed	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Goats	0.9	0.8	0.7						
Poultry	261.3	268.3	275.1	284.2	291.7	296.6	301.3	308.2	314.5
Hens > 1 yr	53.7	51.3	55.9	59.1	59.8	57.5	58.0	58.9	61.1
Pullets laying	56.2	60.0	57.9	59.4	60.9	61.9	61.4	62.4	63.8
Pullets > 3 mo	8.4	8.4	8.4	7.6	7.9	7.8	7.7	8.7	9.7
Pullets < 3 mo	6.1	6.9	6.8	7.4	7.0	7.4	7.3	8.1	8.2
Chickens	2.3	2.4	2.5	2.7	2.7	2.8	2.6	2.8	2.8
Broilers	97.7	102.3	106.7	111.6	117.0	122.1	126.6	129.4	132.2
Other (Lost)	0.8	0.8	0.8	0.8	0.8	1.4	1.3	1.0	1.1
Other (Sold)	9.3	9.3	9.2	8.9	8.7	8.1	7.8	8.4	8.4
Turkeys	26.7	26.9	27.0	26.8	26.9	27.5	28.5	28.4	27.1
Horses	28.8	28.8	29.8	30.0	30.5	30.5	30.8	31.3	31.3